LETTERS TO THE EDITOR

A Travelling Wave Linear Accelerator with R.F. Power Feedback, and an Observation of R.F. Absorption by Gas in Presence of a Magnetic Field

A travelling wave linear accelerator usually consists of a high frequency power source feeding power into a waveguide accelerating tube which is terminated by a dummy load to absorb without reflection the power reaching the output end. It has been shown (Harvie 1948) that there is an optimum length of accelerating tube, which corresponds to an attenuation of approximately 1·25 nepers, but unfortunately there are sometimes practical difficulties in making accelerators as long as the optimum length. This note describes means for overcoming some of these difficulties, in which an accelerator of less than optimum length retains its efficiency by utilizing the power which is usually wasted in the dummy load.

The system is shown diagrammatically in Figure 1, in which arrows indicate the direction of power flow. Power is fed back from the output end of the accelerator and combined with the power from the source in a suitable bridge circuit. It is sometimes

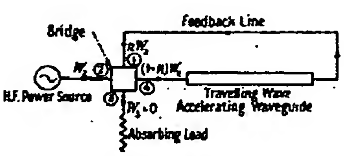

Figure 1. Diagrammatic arrangement of linear accelerator with feedback.

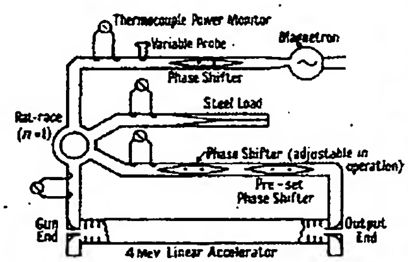

Figure 2. Feedback system applied to 4 MeV. linear accelerator.

desirable that arms (1) and (2) of the bridge should be mutually conjugate, in order to make the impedance presented to the source constant during a transient building-up period and independent of the accelerator characteristics. It can then be shown that the bridge circuit must include a dissipative element which is shown connected to arm (3) externally; under steady state conditions no power is dissipated in this element. Steady state power fluxes are shown on the diagram; the power flux entering the accelerator $(1+n)W_2$, is always greater than the power supplied by the source and n is determined by the attenuation of the accelerator. Calculations show that the "efficiency" of the accelerator, V^2/WL, increases as the length is diminished and is slightly greater than that of an optimum length accelerator with a dummy load at the end.

Bridges of the type required have been studied previously (Tyrell 1947, Smullin and Montgomery 1948) for the special case where $n=1$, and examples will be familiar under the names of "magic T" and "Rat-race". There seems to be no great difficulty in designing bridges along similar lines for other values of n.

In a pulse operated system it is necessary for waves to make several transits of the accelerator and feedback loop, after application of the pulse, before steady state conditions are approached. Calculations show that the build-up time is independent of the length and is approximately the same as in a conventional accelerator of optimum length. If the frequency of the source is varied the power fed back from the end does not return in the correct phase and the circulating power is reduced. It can be shown that the permissible frequency bandwidth is again approximately the same as in an ordinary accelerator of

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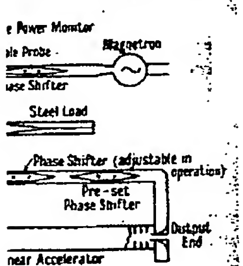

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optimum length; however, by adding an adjustable phase changer in the feedback path it is possible to maintain the correct circulating power at any frequency and the bandwidth is then only limited by the wave-to-electron phasing in the usual way.

An advantage of the system is that the accelerator can be made appreciably shorter than the optimum length without losing efficiency, which leads to increased dimensional tolerances on the waveguide. A shorter waveguide also has a wider frequency bandwidth, as far as phasing of the wave to electrons is concerned, and it may also be an advantage in practice to allow the frequency of the source to vary as it will within this band while the operating conditions are kept right by adjusting the phase changer in the feedback loop.

For the case of a bridge circuit designed for $n=1$, theoretical curves can be plotted for the power in the various arms of the bridge when the phase and attenuation in the accelerator loop are varied. Experimental confirmation has been obtained at low C.W. power with a mock-up system on a wavelength of 3·2 cm., using a normal $n=1$ "Rat-race" and about 30 wavelengths of rectangular waveguide to represent in some measure the corrugated waveguide. A method has also been worked out theoretically and confirmed experimentally for obtaining a suitable signal which will reset the phase shifter in the feedback arm when the magnetron frequency changes.

It has also been possible to try out the $n=1$ system on the 4 MeV. linear accelerator (Fry *et al.* 1948) since the R.F. loss in the accelerator is about 2·5 db. and can be made up to 3 db. with beam loading. The experiment had unfortunately to be carried out in a very short time and the external waveguide components were not matched as well as they should have been; consequently the thermocouple power monitors could not be relied upon to within 20%, although they were partly compensated for by the presence of standing waves. It was not therefore possible to verify the power fluxes in all parts of the system. However, independent measurements showed that the accelerator operated as if it had an input R.F. power flux of 2·1–2·2 MW. when the magnetron power was only about 1·4 MW. The energy spectrum was identical to that previously obtained with the same input power but without feedback. The maximum power which could be obtained in the accelerator was 2·4 MW. and, with a somewhat lower frequency than normal, the mean energy was raised to 4·5 MeV. but with more than twice the normal spectrum width. These experiments indicated that a well matched system would work as predicted, but with one reservation—that a somewhat better vacuum is required than for an equivalent accelerator without feedback.

It was noticed that the loss in the corrugated waveguide soon after applying the R.F. power but without the gun in operation was very greatly increased when the focusing field was switched on, and moreover the effect happened quite critically at about one-third of the normal focusing field and was not confined to any particular spot along the length of the corrugated waveguide. It has been checked that the power leaving the accelerator falls in the same manner for the system without feedback, but since there is no reaction on the input power its effect on this particular accelerator is not serious and had therefore not been observed before. The effect may be due to the presence of positive ions or electrons which spiral under the influence of the focusing field and consequently abstract very much greater quantities of energy from the R.F. wave than if they drifted straight to the walls of the tube. As the vacuum cleans up the effect entirely disappears and the operation is as predicted.

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